UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

October 22, 2009

The Honorable Gregory B. Jaczko
Chairman
U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: CLOSURE OF STEAM GENERATOR ACTION PLAN ITEMS 3.1k, 3.4, 3.5, 3.10, 3.11, and 3.12

Dear Chairman Jaczko:

During the 566th meeting of the Advisory Committee on Reactor Safeguards, October 8-10, 2009, we met with representatives of the NRC's staff from the Office of Nuclear Regulatory Research (RES) and the Office of Nuclear Reactor Regulation (NRR) to review the closeout of several tasks in the Steam Generator Action Plan. Our Subcommittee on Materials, Metallurgy, and Reactor Fuels also reviewed these activities at its meeting on September 24-25, 2009. We had the benefit of the documents referenced.

RECOMMENDATIONS

1. Research activities within the Steam Generator Action Plan focusing on induced steam generator tube rupture (Items 3.1k, 3.4, 3.5, 3.10, and 3.12) can be concluded. Additional research needed in this area can be identified through the normal "user need" process.

2. As a part of closing items of the Steam Generator Action Plan dealing with the induced steam generator tube rupture issue, staff should prepare a summary document that describes the current state of understanding of this issue and the technical issues that remain to be resolved for specific plant applications.

3. Our previous endorsement of the resolution of Generic Safety Issue -163, "Multiple Steam Generator Tube Leakage," in our May 20, 2009 report means that item 3.11 of the Steam Generator Action Plan can be closed.

BACKGROUND

Steam generator tubes constitute an important fraction of the primary coolant system pressure boundary of pressurized water reactors. Preservation of the integrity of these tubes has been recognized as important to safety since pressurized water reactors were first introduced as a means to generate electrical power. Indeed, rupture of a steam generator tube is a design basis accident considered in the licensing and regulation of pressurized water reactors. Steam generator tube rupture events have occurred and in all cases the plants have coped with these events.

Steam generator tube rupture events accompanied by additional failures can lead to core melting. Radionuclides released from degrading reactor fuel will vent through the ruptured steam generator tubes into plant buildings or directly to the environment without mitigation by natural processes or engineered safety features in the reactor containment. The NRC's risk assessment of representative nuclear power plants published in 1990 (NUREG-1150, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants") confirmed findings of the first probabilistic risk assessment of nuclear power plants (WASH-1400) that accidents in which radionuclide releases bypass the reactor containment can dominate the risk posed by nuclear power plants even though such accidents are not as probable as other accidents leading to core degradation.

Rupture of steam generator tubes during power plant operations can occur by wear, loose parts in the steam generator, or by corrosion. Over the years of pressurized water reactor operation, the corrosion of steam generator tubes has received quite a lot of attention both from licensees and from the NRC. The dominant mechanism of steam generator tube corrosion has evolved as a result of changes in water chemistry and steam generator tube materials from predominantly wastage of material to predominantly stress corrosion cracking. Consequently, the methods for inspection of tubes during plant outages have evolved. Though current methods of tube inspection by eddy current techniques are very sophisticated, there is some small probability that excessively degraded tubes can be left in service.

Risk studies sponsored by the NRC raised the question of whether core degradation accidents initiated by means other than steam generator tube rupture might progress in such a way that degraded tubes ruptured. That is, core degradation accidents might evolve into accidents where radionuclide releases could bypass the mitigative capabilities of the reactor containment. During our review of the alternative criterion for repair and replacement of steam generator tubes, we asked the staff to examine the phenomena associated with what came to be called "induced steam generator tube rupture accidents." Staff agreed to undertake the necessary investigations within its Steam Generator Action Plan.

The threat to tube integrity during the progression of a core meltdown accident arises from the natural convection of hot steam and hydrogen from the core region to the steam generators. Two limiting patterns for such natural convection are depicted schematically in Figure 1. On the left of this figure, the loop seals are open and full convective flow through the tubes can occur. On the right, loop seals are shown to be intact. A very complicated countercurrent flow of gas through the hot leg and the steam generator develops in this case. The concern for both possible natural convection patterns is that heat loads placed on the tubes by convection currents could be sufficient that tubes will fail by creep rupture.

Convection currents that develop when the loop seals are open impose the highest heat loads on the steam generator tubes and under these conditions failure is likely. Opening of the loop seals is a complicated issue that depends very much on specific design features of the reactor coolant system. We have not reviewed capability of existing accident analysis computer codes to predict the clearing of loop seals during accident progression.

For many plants, it is thought more likely that loop seals will remain intact for much of the core damage progression. Heat loads imparted to the steam generator tubes in the case of countercurrent natural circulation are mitigated by the mixing in the lower plenum of the steam generator of hot gases coming from the core region with cooler gases in the return flow.

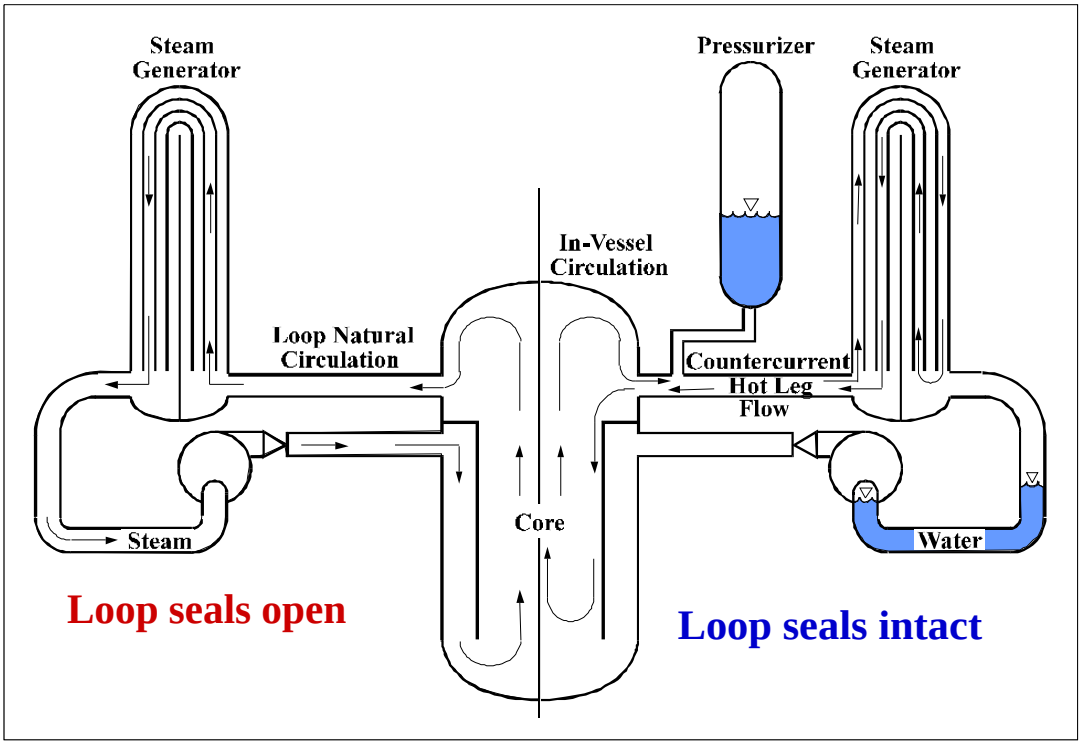

Figure 1 - Limiting patterns for natural circulation of hot gases from the degrading reactor core through steam generators. Arrows indicate the direction of gas flow. On the left, "loop seals" are open and full loop natural circulation takes place. On the right, "loop seals" are intact and counter current natural circulation through the steam generator takes place.

Because heat up of the tubes is slower in the case of countercurrent natural circulation, thermal threats to other portions of the reactor coolant system become important. Particularly vulnerable are regions of the piping near the nozzle between the hot leg and the vessel and the surge line connecting the hot leg to the pressurizer. Creep rupture at these locations would allow radionuclides released from the core to vent into the reactor containment where they could be mitigated by natural processes and by engineered safety features of the containment. That is, failures at the nozzle or at the surge line could prevent release of radioactivity that bypassed containment.

DISCUSSION

The NRC staff has had for several years a Steam Generator Action Plan to focus research on a variety of issues that have arisen in connection with the steam generator tubes. Episodically, the staff has presented results of their work within this Action Plan and closed issues with our agreement. At our recent meeting, the staff presented its findings and asked for our concurrence in closing remaining items in the Action Plan especially those connected with the thermal hydraulics and risk of induced steam generator tube rupture events.

Closure of items in the Steam Generator Action Plan does not imply that there is no further need for investigation. Closure simply means that the pertinent issues have been explored

sufficiently. Further research should be undertaken following the usual user need process and should be tailored to facilitate the regulatory process. Research in the future should address quantifying uncertainties in predictions of phenomena.

Thermal Hydraulics of Induced Steam Generator Tube Rupture

Staff has conducted sophisticated analyses of the countercurrent natural circulation and the thermal threats to the integrity of the reactor coolant system (Steam Generator Action Plan Item 3.4). For the example case studied by the staff, it has been found that failure of the hot leg near the nozzle will occur before failure of the steam generator tubes. The time interval between failure of the nozzle and failure of the tubes is not large (~ 6 minutes). This time interval is dependent on details of the design of the lower plenum of the steam generator. What has been found for the example case studied by the staff cannot be applied generically without consideration of the design details. An important finding of the work, however, is that even if tube failure precedes hot leg failure, depressurization of the reactor coolant system through up to eight tubes may be slow enough that hot leg failure eventually occurs and bypass releases of radionuclides are limited. Of course, thermal failure of many tubes could lead to a very large, unmitigated release before failures could occur elsewhere in the reactor coolant system.

The investigation of thermal hydraulics of natural convection has involved pioneering work by the staff to couple results of computational fluid dynamics (CFD) with systems level accident analyses using the RELAP computer code. Some issues remain to be resolved including:

- Demonstration of valid means for predicting loop seal clearing
- Validation of computational methods for analyzing the wanderings of hot plumes rising through the steam generator tube bundle that limit temperature rise on any one tube

Nevertheless, we find the work done by the staff to be impressive. Further research can be done in connection with specific regulatory objectives. Item 3.4 of the Steam Generator Action Plan can be closed.

Risk of Induced Steam Generator Tube Rupture

The staff has undertaken an effort to ascertain whether induced steam generator tube rupture is sufficiently probable that it should be considered in probabilistic risk assessments. To some extent, this has become a moot point since consideration of accident progression to steam generator tube rupture is mandated by the current standards for probabilistic risk assessment. Staff has shown that it is possible to “post process” results of risk assessments to assess the probability of induced steam generator tube rupture. When the staff has done this, it has found the risk is not negligible. This is a useful finding. On the other hand, the post processing is not the preferred method for assessing induced steam generator tube rupture. Rather, the risk of induced steam generator tube rupture should be derived from an integrated analysis of accident progression within the probabilistic risk assessment. Nevertheless, staff has done enough to address items 3.5 and 3.12 of the Steam Generator Action Plan. These items may be closed. We are confident that user needs will lead to further research to develop methods that can be used by line organizations to assess the probability of induced steam generator tube rupture for specific plants.

Multiple Tube Failures

All steam generator tube rupture events that have occurred in the past have involved a single tube. Multiple tube failures would be more hazardous events because reactor coolant water could be expelled rapidly through the tubes. Water inventory for the emergency core cooling system would be depleted. Core meltdown, then, would be inevitable. Such multiple tube ruptures could occur by movement of the tube support plates as a consequence of a design basis break of the main steamline. Staff has examined this possibility and concluded that tube support plates are locked in place either by corrosion products or by deliberate measures so that the deflection necessary to produce tube failures cannot occur. Item 3.1k of the Steam Generator Action Plan can be closed.

CONCLUSION

Staff has developed a much better understanding of the induced steam generator tube rupture process through the research done as a part of its Action Plan. Closure of the remaining items will largely conclude the work planned in connection with the Action Plan. Documentation of the understanding the staff has developed is, however, dispersed. The issue is of sufficient interest that staff should take the opportunity to summarize the understanding it has developed in a single, readily available document that provides a guide to all the relevant results and sufficient detail that the depth of understanding can be assessed. The summary should include pertinent findings from Action Plan items that have been closed previously.

Dr. William J. Shack did not participate in the Committee's deliberations regarding this matter.

Sincerely,

/RA/

Mario V. Bonaca

REFERENCES

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